Appendix D
Development of Site-Specific Response Spectra Based on Random Earthquake Analysis

D-1. Random Earthquake Analysis

A "random earthquake" analysis is performed when it is desired to estimate the response spectrum at the site due to a randomly located ("floating") earthquake occurring within the vicinity of the site when its location cannot be ascribed to a specific geologic structure at a specific distance from the site. This type of analysis had its origin in estimating ground motions at nuclear power plant sites in the eastern United States, and it has been used for other facilities and locations as well. The most common procedure used is to conduct a statistical analysis of response spectra of available near-source recordings (typically within a source-to-site distance of 25 km) from earthquakes within a magnitude band centered on the target magnitude (typically plus or minus one-half magnitude unit). A random earthquake analysis can also be performed using response spectra attenuation relationships appropriate for the site conditions and tectonic environment where the site is located. It should be noted that in many cases sufficient recordings may not be available to conduct a random earthquake analysis using statistical analysis of response spectra; in these cases a random earthquake analysis can be carried out using only appropriate attenuation relationships. It may be desirable to conduct the random earthquake analysis using both the statistical analysis procedure and the procedure using attenuation relationships. The following sections illustrate the use of the statistical procedure and the attenuation relationships in conducting a random earthquake analysis.

D-2. Statistical Analysis of Recorded Strong Motion Data

a. As mentioned previously, when the design earthquake is specified as a random event occurring in the site vicinity, the available near-source recordings from earthquakes with magnitudes close to the target magnitude are analyzed statistically to obtain estimates of the site-specific spectra. In this example, the site-specific ground motions for a random shallow crustal earthquake of moment magnitude 6.0 were evaluated by conducting a statistical analysis of response spectra computed from accelerograms recorded during earthquakes of magnitude M 6.0 ± 0.5 at source-to-site distances R of approximately 25 km or less. Only recordings from stations located on rock or rocklike material (shear wave velocity $\geq$ 2,500 fps) were used. The records available for this analysis are listed in Table D-1 in terms of the earthquake name, date, type of faulting, magnitude, station number, closest source-to-site distance, the component directions, and the peak acceleration value for each accelerogram. A total of 30 records (60 horizontal components) were selected from earthquakes in the magnitude range of 5.5 to 6.5. A scattergram showing the magnitude-distance distribution of the records used in the analysis is shown in Figure D-1. The mean closest source-to-site distance of the recordings is 13.7 km. If an earthquake is assumed to occur randomly with a uniform distribution within a 25-km-radius circle about the site, then the mean distance should be 16.7 km. The probability of an event occurring within a specific distance band is equal to the ratio of the area within the distance band to the total area in the 25-km-radius circle. These probabilities are compared in Table D-2 with percentages of the data set lying in various distance bands.

b. As can be seen, the distribution of data is not the same as that expected for a random event within a circle. To adjust the distribution, a weighted statistical analysis was performed with the spectra in each distance band assigned a weight such that their contribution to the total is equal to the probability of a random event occurring in the appropriate distance band. The statistical analysis of this weighted

Table D-1
Database for Statistical Analysis for Shallow Crustal Random Earthquake (M 5.5 - 6.5, R ≤ 25 km, Rock Site Recordings (60 Records Total)

Earthquake	Date	RUPT	M_W	ML	STAN	CLD	COMP	PGA
Parkfield, CA	6/27/66	StrikeSlip	6.1	5.6	1438	9.9	N65W	0.282
Parkfield, CA	6/27/66	StrikeSlip	6.1	5.6	1438	9.9	S25W	0.411
Koyna, India	12/10/67	StrikeSlip	6.3	6.3	9001	3.0	LONG	0.631
Koyna, India	12/10/67	StrikeSlip	6.3	6.3	9001	3.0	TRAN	0.490
Oroville, CA (M)	8/1/75	Normal	5.9	5.7	1051	9.5	N53W	0.103
Oroville, CA (M)	8/1/75	Normal	5.9	5.7	1051	9.5	N37E	0.108
Friuli Sequence	9/11/76	Thrust	5.5	5.5	8022	15.5	NORT	0.042
Friuli Sequence	9/11/76	Thrust	5.5	5.5	8022	15.5	EAST	0.071
Friuli Sequence	9/11/76	Thrust	5.9	5.9	8022	14.5	NORT	0.091
Friuli Sequence	9/11/76	Thrust	5.9	5.9	8022	14.5	EAST	0.093
Friuli Sequence	9/15/76	Thrust	6.1	6.1	8022	9.0	NORT	0.069
Friuli Sequence	9/15/76	Thrust	6.1	6.1	8022	9.0	EAST	0.123
Coyote Lake, CA	8/6/79	StrikeSlip	5.7	5.7	1445	3.2	N70E	0.230
Coyote Lake, CA	8/6/79	StrikeSlip	5.7	5.7	1445	3.2	N20W	0.160
Coyote Lake, CA	8/6/79	StrikeSlip	5.7	5.7	1408	9.3	S40E	0.130
Coyote Lake, CA	8/6/79	StrikeSlip	5.7	5.7	1408	9.3	N50E	0.100
Coyote Lake, CA	8/6/79	StrikeSlip	5.7	5.7	1413	3.1	S40E	0.340
Coyote Lake, CA	8/6/79	StrikeSlip	5.7	5.7	1413	3.1	N50E	0.420
Imperial Valley (M)	10/15/79	StrikeSlip	6.5	6.6	286	26.0	S45E	0.210
Imperial Valley (M)	10/15/79	StrikeSlip	6.5	6.6	286	26.0	N45E	0.120
Imperial Valley (M)	10/15/79	StrikeSlip	6.5	6.6	6604	23.5	N57W	0.157
Imperial Valley (M)	10/15/79	StrikeSlip	6.5	6.6	6604	23.5	S33E	0.166
Mammoth Lakes - A	5/25/80	StrikeSlip	6.2	6.1	54214	15.5	090	0.079
Mammoth Lakes - A	5/25/80	StrikeSlip	6.2	6.1	54214	15.5	000	0.125
Mammoth Lakes - A	5/25/80	StrikeSlip	6.2	6.1	54214	15.5	090	0.068
Mammoth Lakes - A	5/25/80	StrikeSlip	6.2	6.1	54214	15.5	000	0.109
Mammoth Lakes - C	5/25/80	StrikeSlip	6.0	6.1	54214	19.7	090	0.075
Mammoth Lakes - C	5/25/80	StrikeSlip	6.0	6.1	54214	19.7	000	0.088

Note:

RUPT = Type of Faulting
M_W = Moment Magnitude
ML = Local Magnitude
STAN = Station No.
CLD = Closest Distance (km)
COMP = Component
PGA = Peak Ground Acceleration (g)

(Continued)

Table D-1 (Concluded)

Earthquake	Date	RUPT	M_w	ML	STAN	CLD	COMP	PGA
Mammoth Lakes - C	5/25/80	StrikeSlip	6.0	6.1	54214	19.7	090	0.060
Mammoth Lakes - C	5/25/80	StrikeSlip	6.0	6.1	54214	19.7	000	0.112
Mammoth Lakes C01	5/25/80	StrikeSlip	5.7	5.7	54214	14.4	090	0.063
Mammoth Lakes C01	5/25/80	StrikeSlip	5.7	5.7	54214	14.4	000	0.099
Mammoth Lakes C01	5/25/80	StrikeSlip	5.7	5.7	54214	14.4	090	0.043
Mammoth Lakes C01	5/25/80	StrikeSlip	5.7	5.7	54214	14.4	000	0.083
Mammoth Lakes - D	5/27/80	StrikeSlip	6.0	6.2	54214	20.0	090	0.207
Mammoth Lakes - D	5/27/80	StrikeSlip	6.0	6.2	54214	20.0	000	0.208
Mammoth Lakes - D	5/27/80	StrikeSlip	6.0	6.2	54214	20.0	090	0.180
Mammoth Lakes - D	5/27/80	StrikeSlip	6.0	6.2	54214	20.0	000	0.219
Mammoth Lakes - D	5/27/80	StrikeSlip	6.0	6.2	54424	24.5	160	0.119
Mammoth Lakes - D	5/27/80	StrikeSlip	6.0	6.2	54424	24.5	070	0.093
Mexicali Valley, MX	6/9/80	StrikeSlip	6.4	6.4	6604	8.5	N45E	0.611
Mexicali Valley, MX	6/9/80	StrikeSlip	6.4	6.4	6604	8.5	S45E	0.603
Coalinga, CA AS12	07/21/83	Thrust	5.9	6.0	67	9.5	N00E	0.960
Coalinga, CA AS12	07/21/83	Thrust	5.9	6.0	67	9.5	N90W	0.838
Coalinga, CA AS12	07/21/83	Thrust	5.9	6.0	46	15.3	N90E	0.116
Coalinga, CA AS12	07/21/83	Thrust	5.9	6.0	46	15.3	N00E	0.136
Coalinga, CA AS12	07/21/83	Thrust	5.9	6.0	65	11.3	N00E	0.219
Coalinga, CA AS12	07/21/83	Thrust	5.9	6.0	65	11.3	N90W	0.218
Coalinga, CA AS12	07/21/83	Thrust	5.9	6.0	61	12.4	N00E	0.231
Coalinga, CA AS12	07/21/83	Thrust	5.9	6.0	61	12.4	N90W	0.375
Coalinga, CA AS12	07/21/83	Thrust	5.9	6.0	65	11.3	N00E	0.194
Coalinga, CA AS12	07/21/83	Thrust	5.9	6.0	65	11.3	N90W	0.219
Morgan Hill, CA	04/24/84	StrikeSlip	6.2	6.2	57217	0.1	N75W	1.304
Morgan Hill, CA	04/24/84	StrikeSlip	6.2	6.2	57217	0.1	S15W	0.707
Morgan Hill, CA	04/24/84	StrikeSlip	6.2	6.2	57383	11.8	N90E	0.293
Morgan Hill, CA	04/24/84	StrikeSlip	6.2	6.2	57383	11.8	N00E	0.228
Morgan Hill, CA	04/24/84	StrikeSlip	6.2	6.2	47379	16.2	N40W	0.100
Morgan Hill, CA	04/24/84	StrikeSlip	6.2	6.2	47379	16.2	S50W	0.073
North Palm Springs	7/8/86	StrikeSlip	5.9	5.9	12206	25.8	N90E	0.119
North Palm Springs	7/8/86	StrikeSlip	5.9	5.9	12206	25.8	N00E	0.145

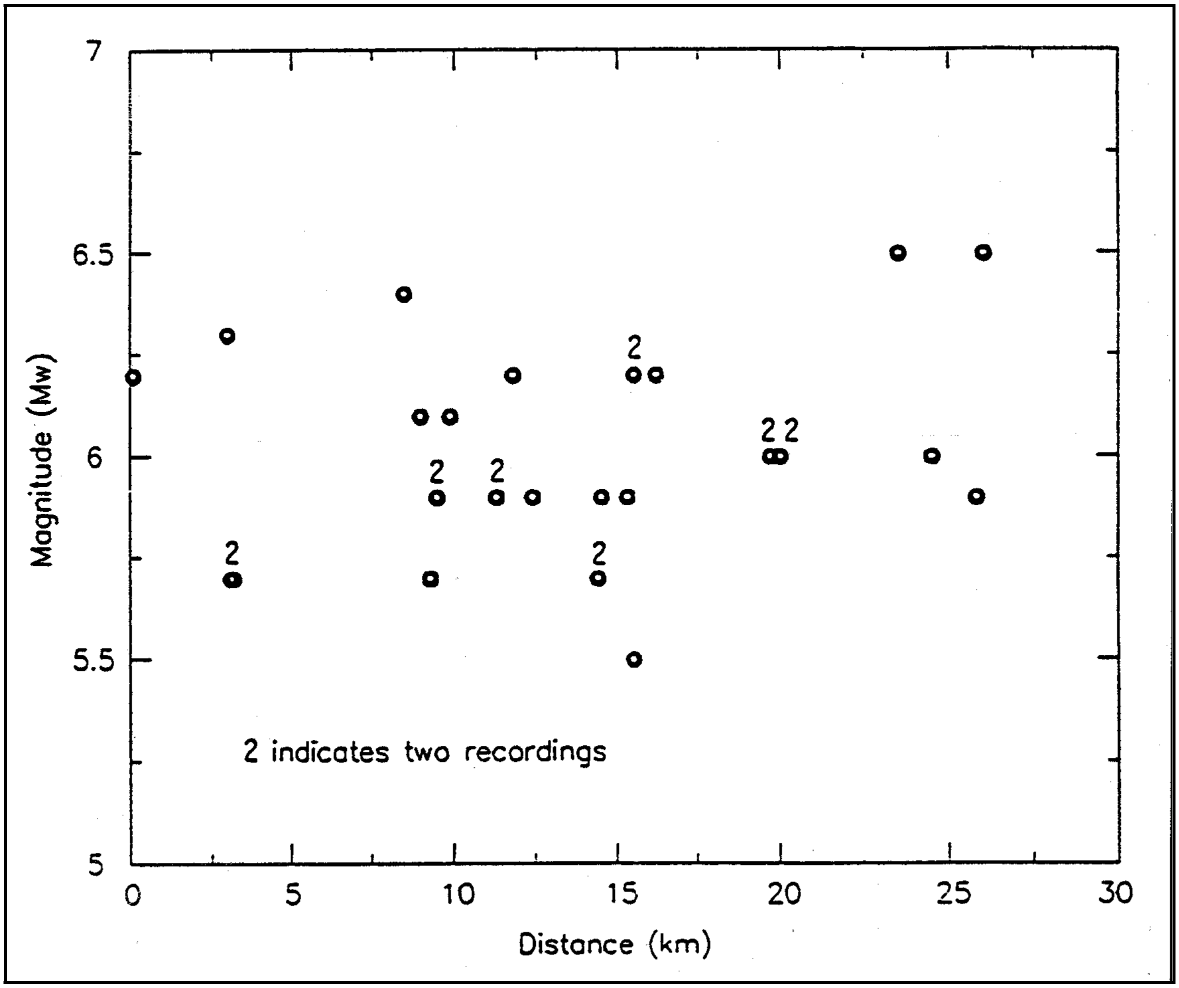

Figure D-1. Scattergram of recordings used in the example analysis

Table D-2
Probability of an Event Occurring in a Distance Band Versus Percentage of Data Set in Distance Band

Distance Range, km	Probability of a Random Event in Distance Band	Fraction of Data Set in Distance Band
0 - 5	0.04	0.133
5 - 10	0.12	0.200
10 - 15	0.20	0.233
15 - 20	0.28	0.233
20 - 25	0.36	0.200

data set was performed on the logarithm of spectral pseudo-relative velocity (PSRV). Several studies (e.g., Esteva 1969; McGuire 1974; Campbell 1981; Abrahamson 1987) have shown that the variability in recorded ground motions is best modeled by a lognormal distribution. The results of the analysis are shown in Figure D-2 in terms of the median (50th percentile) and median plus one standard deviation (84th percentile) of the fitted lognormal distribution for a damping value of 5 percent.

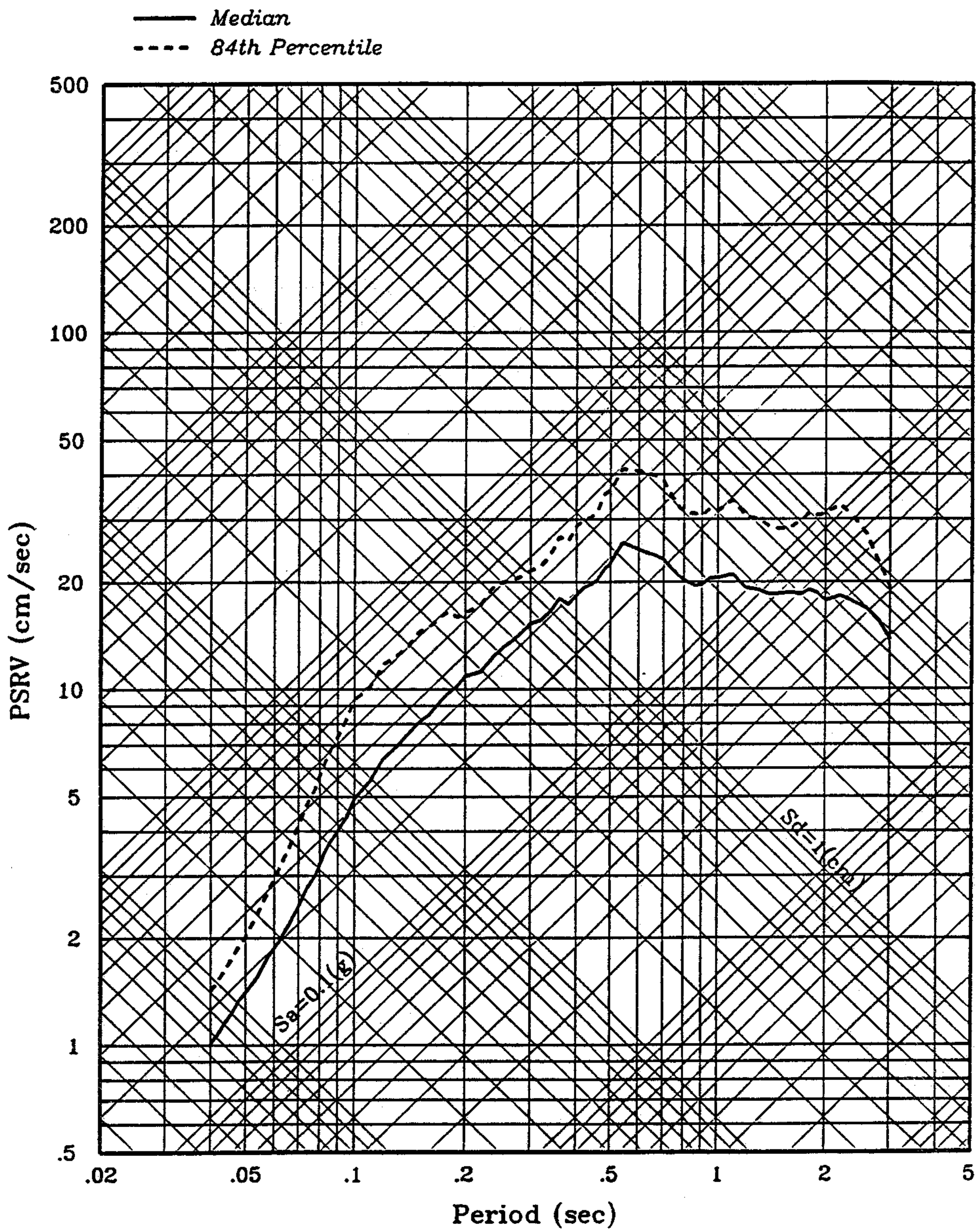

Figure D-2. Horizontal response spectra (5 percent damping) from statistical analysis of selected rock recordings, shallow crustal random earthquake (M6 at R ≤ 25 km)

D-3. Estimates of Site-Specific Spectra Using Attenuation Relationships

a. As mentioned in paragraph D-2, attenuation relationships can be used to estimate the median and 84th-percentile ground motions for an event occurring randomly within a specified distance from the site. In this approach, the mean log ground motion level, $E\,[\ln(Y)]$, is given by

$$E\,[\ln\,(Y)] = \int_M \int_R f(M) \bullet f(R) \bullet E\,[\ln\,(Y) \mid m,r]\;dr\;dm \tag{D-1}$$

where

$f(M)$ = probability density function for the event magnitude

$f(R)$ = probability density function for the distance to a random event

$E\,[\ln\,(Y) \mid m,r]$ = mean log ground motion level given by the attenuation relationship for a specific magnitude m and distance r

The 84th-percentile ground motion level is found by solving iteratively for the value, y, that satisfies the equation

$$\int_M \int_R f(M) \bullet f(R) \bullet P(Y{>}y \mid m,r)dr\;dm = 0.8416 \tag{D-2}$$

where $P(Y{>}y \mid m,r)$ is given by the cumulative normal probability function assuming the ground motions are lognormally distributed about the mean log value specified by the attenuation relationship.

b. This approach can be viewed as the use of an attenuation relationship to simulate a very large artificial data set with the distance distribution of earthquake magnitudes and source-to-site distances, and then performing a statistical analysis of that data set. In this case, because the simulated data will have the desired distance distribution, weighting functions are not necessary.

c. This approach is illustrated for a rock site in the eastern United States located within a large seismic source zone where no active faults were identified. The site is the same as for Example 5 in Appendix G. The probability distribution for the earthquake magnitude of the maximum credible earthquake (MCE) in the source zone is (probabilities in parentheses): m_b 5.5 (0.06), m_b 6 (0.47), m_b 6.5 (0.27), m_b 7 (0.15), m_b 7.5 (0.05) (mean value m_b 6.3, where m_b is body wave magnitude). The MCE was assumed to occur randomly within a 25-km-radius circle around the site. The length of fault rupture associated with an MCE of a given magnitude was incorporated into the development of the distance distribution. This procedure produces a smaller average distance to a random event within the circle than does a point source assumption. The attenuation relationships for peak ground acceleration and response spectral accelerations of rock motions of Electric Power Research Institute (1993) (later published as Toro, Abrahamson, and Schneider (1997), Tables 3-1 and 3-3 of this manual) were used. These relationships are applicable to rock sites in the eastern United States. The relationships are characterized by increased high-frequency ground motions compared with ground motions at western United States rock sites (see paragraph 3-4 of this manual). As described in Example 5 in Appendix G, an adjustment to these relationships was made to account for somewhat softer rock at the site than the hard rock applicable to the attenuation relationships. The median response spectrum for MCE ground motions at the site resulting from the analysis is shown in Figure D-3.

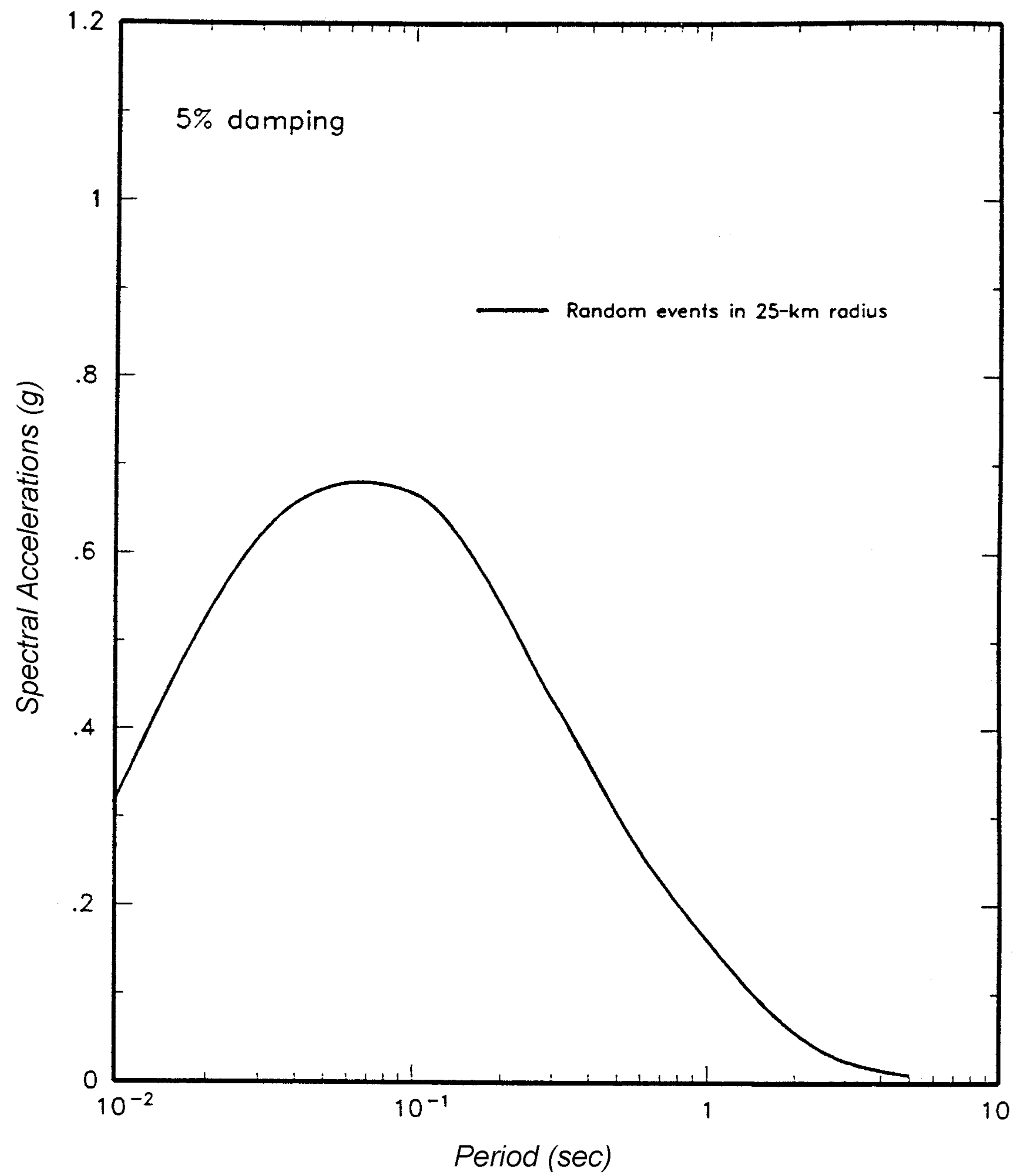

Figure D-3. Horizontal site response spectrum for MCE in seismic source zone Iapetan Rifted Margin in vicinity of site